Year: 2008

Strength of CAD/CAM-generated esthetic ceramic molar implant crowns

Wolf, D ; Bindl, A ; Schmidlin, P R ; Lüthy, H ; Mörmann, W H

Abstract: PURPOSE: One-visit in-office CAD/CAM fabrication of esthetic ceramic crowns as a superstructure for posterior implants is quite new. The aim of the study was to evaluate the strength of esthetic ceramic CAD/CAM crowns with varied occlusal thickness and seated with adhesive and nonadhesive cements on titanium and zirconia abutments. MATERIALS AND METHODS: Esthetic ceramic CAD/CAM-generated molar crowns (n = 15 per group) with occlusal thicknesses of 0.5 mm and 1.5 mm were seated on titanium (1) and zirconia (2) abutments: noncemented (a) and with nonadhesive cement (b) or 2 adhesive resin-based cements (c) and (d). In addition, 15 molar crowns with 5.5-mm occlusal thickness were seated on short zirconia abutments (3) using cements (c) and (d). All crowns had the identical occlusal morphology and were loaded with a crosshead speed of 0.5 mm/min until fracture. Load data were analyzed using 2-way ANOVA, the Scheffé test, and Weibull probability of failure analysis. RESULTS: Fracture loads of 1.5-mm occlusal thickness crowns (a, b, c, d) were higher ($P < .001$) than those of 0.5-mm crowns (except for group ld). Occlusal 5.5-mm crowns on short zirconia abutments had similar (2c) or less (2d) strength than the respective 1.5-mm crowns. Nonadhesive crowns (1b, 2b) were weaker ($P < .001$) than adhesive crowns (1c, 1d, 2c, 2d). Fracture loads of 0.5- and 1.5-mm crowns were significantly higher on titanium than on zirconia abutments with both cements. Adhesive cement d generally showed higher fracture loads than c on both titanium and zirconia. CONCLUSION: Esthetic ceramic CAD/CAM molar implant crowns gained high strength with adhesive cements on both titanium and zirconia implant abutments compared to nonadhesive cementation.

Originally published at:
Wolf, D; Bindl, A; Schmidlin, P R; Lüthy, H; Mörmann, W H (2008). Strength of CAD/CAM-generated esthetic ceramic molar implant crowns. International Journal of Oral and Maxillofacial Implants, 23(4):609-617.

Strength of CAD/CAM-Generated Esthetic Ceramic Molar Implant Crowns

Daniel Wolf[a], Andreas Bindl[a], Patrick R. Schmidlin[b], Heinz Lüthy[c] and Werner H. Mörmann[a*]

[a]Division of Aesthetic and Computer Restorations, [b]Division of Periodontology, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental and Oral Medicine, University of Zurich, Zurich, Switzerland

[c]Department of Fixed and Removable Prosthodontics and Dental Materials, Center for Dental and Oral Medicine, University of Zurich, Zurich, Switzerland

Short title:

Strength of CAD/CAM Implant Crowns

Dr. Daniel Wolf, Dr. Andreas Bindl, Dr. Patrick R. Schmidlin, Prof. Werner H. Mörmann:
Divisions of Computer Restorations and Periodontology, Department of Preventive Dentistry, Periodontology and Cariology, Center for Dental and Oral Medicine, University of Zurich, Plattenstrasse 11, CH-8032 Zurich, Switzerland

Prof. Heinz Lüthy:
Department of Fixed and Removable Prosthodontics and Dental Materials, Center for Dental and Oral Medicine, University of Zurich, Plattenstr.11, CH-8032 Zurich, Switzerland

****Corresponding author**:
Prof. Dr. Werner Mörmann, Plattenstr.11, CH-8032 Zurich, Switzerland
Tel.: +41-44-6343360; Fax: +41-44-6344307
E-mail address: werner.moermann@zzmk.unizh.ch

Keywords

- CAD/CAM implant crowns
- CAD/CAM esthetic ceramic
- Adhesive cementation
- Fracture load
- Ttanium abutments
- Zirconia abutments

Abstract

Purpose. One visit in-office CAD/CAM fabrication of esthetic ceramic crowns as a superstructure for posterior implants is quite new. Aim of the study was to evaluate the strength of esthetic ceramic CAD/CAM crowns with varied occlusal thickness and seated with adhesive and non-adhesive cements on titanium and zirconia abutments.

Materials and Methods. Esthetic ceramic CAD/CAM generated molar crowns (n=15 per group) with occlusal thicknesses of 0.5 mm and 1.5 mm were seated on titanium (1) and zirconia (2) abutments: non-cemented a), non-adhesive b), and with two adhesive resin-based cements c) and d). In addition, 15 molar crowns with 5.5 mm occlusal thickness were seated on short zirconia abutments (3) using cements c) and d). All crowns had the identical occlusal morphology and were loaded with a crosshead speed of 0.5 mm/min until fracture. Load data were analyzed using two-way ANOVA, Scheffé test and Weibull probability of failure analysis.

Results. Fracture loads of 1.5 mm occlusal thickness crowns (a, b, c, d) were higher ($P<0.001$) than those of 0.5 mm crowns except group 1d). Occlusal 5.5 mm crowns on short zirconia abutments had similar (2c) or less (2d) strength than the respective 1.5 mm crowns. Non-adhesive crowns (1b, 2b) were weaker ($P<0.001$) than adhesive crowns (1c, 1d, 2c, 2d). Fracture loads of 0.5 & 1.5 mm crowns were signifticantly higher on titanium than on zirconia abutments with both cements. Adhesive cement d generally showed higher fracture loads than c on both titanium and zirconia.

Conclusion: Esthetic ceramic CAD/CAM molar implant crowns gained high strength with adhesive cements on both titanium and zirconia implant abutments compared to non-adhesive cementation.

1. Introduction

In-office CAD/CAM offers the possibility to fabricate esthetic ceramic molar implant abutment crowns during one visit [1]. Titanium has proved itself as a traditional material for posterior implant abutments because of its suitable mechanical properties [2, 3]. To overcome esthetic problems encountered even in the posterior area, high-strength ceramic abutments (Al_2O_3, ZrO_2) have been developed as an alternative [4-6]. Zirconia ceramics are able to fulfil the requirements of strength and biocompatibility needed for implant abutments [7]. YTZP-zirconium oxide (Yttrium-Tetragonal-Zirconia-Polycrystals) has a tetragonal metastabile crystal structure stabilized by addition of 3 to 6 mol% yttrium oxide [8]. Its flexural strength is at or higher than 900 MPa [9,10]. Kelly [11] categorizes CAD/CAM machinable ceramic as particle-filled, glass-matrix esthetic ceramic. Its flexural strength after CAD/CAM machining comes between 103 to 127 MPa according to brand [12].

All-ceramic crowns have been used increasingly as a superstructure on dental implants in recent years [13,14]. Unilateral bite forces in the posterior area vary between 216 N and 847 N [15-17] but also maxima of 1031 N have been reported [18]. Cyclic loading under wet conditions may reduce the initial strength of ceramic by 50% through fatigue [19,20] raising the demands for adequate strength of esthetic ceramic implant abutment crowns. In vitro studies have shown that adhesive cementation of esthetic ceramic CAD/CAM generated crowns on conventional tooth preparations reinforced them against occlusal loading and fracture [21-24]. A survival rate of 94.6% up to 7 years has been reported for CAD/CAM generated esthetic ceramic molar crowns adhesively cemented to natural tooth preparations [25]. CAD/CAM generated esthetic ceramic crowns are now being used clinically on implants [1,26,27].

Molar implant abutments have a perfectly circular diameter of maximum 7.5 mm at the shoulder, forming a small crown basis compared to the large rectangular gingival cross-section of a natural molar of approximately 10x10 mm [28]. Bulging lateral walls compensate for the geometric difference between the abutment- and natural crown basis outlines to restore the natural anatomy of a molar crown (Figures 1 and 2). The lateral wall design of a molar implant crown therefore differs from the wall design of a conventional molar crown preparation [29]. Consequently fracture load data known from esthetic ceramic crowns on tooth preparations may not exactly apply to implant abutment crowns apart from the different physical properties of the abutments. Data on the fracture strength of CAD/CAM generated esthetic ceramic molar crowns on implants are not yet available. We hypothesized that the fracture load of this type of crowns might be affected by the occlusal crown thickness, the abutment material, mode of cementation, type of adhesive cement, and height of the abutment.

The objective of the study was to evaluate the fracture load of esthetic ceramic CAD/CAM generated molar crowns on titanium and zirconia implant abutments.

2. Materials and Methods

Materials and instruments used in this study are listed in Table 1. Titanium (Gingihue) and zirconia (ZiReal) abutments (3i Implant Innovations, Palm Beach, USA) with identical shape were used. Both abutment types had the platform diameter of 5 mm, abutment width 7.5 mm, height 10.5 mm, circular shoulder width of 0.8 mm and were used in their original form for the design of crowns with 0.5 mm and 1.5 mm occlusal wall thickness (Figures 1 and 2). Additionally, occlusally thick (5.5 mm) crowns were evaluated on shortened zirconia abutments (Figure 2c). For this purpose the zirconia abutments were occlusally shortened by 4 mm to the residual height of 2.5 mm above the shoulder using a diamond microsaw (Leica SP 1600, Leica Microsystems, Glattbrugg, Switzerland). The abutments were mounted on titanium implants (Table 1). As shown in Figure 3 the implants were embedded into the center borehole (10 mm depth, 5 mm diameter) at the upper side of polymethylmethacrylate blocks (35 x 35 x 20 mm, Angst und Pfister, Zurich, Switzerland) using self-cure polymethylmethacrylate (Paladur, Heraeus Kulzer, Dormagen, Germany) with additional (10 min) heat (55°C) and pressure (2 bar) polymerisation.

For the CAD design of the crowns the abutments were scanned using a 3D mouthcamera (Cerec, serial-no. 01014, Sirona, Bensheim, Germany). For scanning the occlusal screw access opening of the abutment was filled with wax (Surgident Periphery Wax, Heraeus Kulzer) and the abutment sprayed with titanium dioxide reflective spray (Scan'spray, Dentaco, Bad Homburg, Germany) to create the white-opaque surface necessary for optical 3D scanning. An upper first molar crown was designed using a dental CAD unit (Cerec 3, serial no. 01394, model no. 58 11 000 D 3344, Sirona) and the tooth library mode of the 3D software (R 1500, Sirona). The occlusal surface was designed in such a way that the load transfer steel ball (∅ 12 mm) in the testing machine rested on even point contacts at the internal slopes of the mesio-, distobuccal and lingual cusps (Figure 3) as applied in earlier studies [22, 24]. To enable this, a „bite registration" of the lower hemisphere of the load transfer steel ball was formed in the axial center position right above the screw access opening of the abutment using light cured (60 s) composite (Tetric, Ivoclar Vivadent Schaan, Liechtenstein). The („bite") registration surface was covered with scan'spray (Dentaco) and a 3D optical scan was taken in the „antagonist" mode of the design software. The virtual antagonist registration and the free form tools of the 3D software were employed to establish even contacts between the sample crowns and the load transfer steel ball when loaded (Figure 3).

The occlusal crown thickness at the level of the central main fissure was set to 1.5 mm for the first set of crown data and was reduced to 0.5 mm with the „position tool" for the second crown data set keeping the occlusal morphology unchanged (Figures 1 and 2). The crown with 5.5 mm occlusal thickness was designed using the "correlation" mode by taking an "occlusion" optical 3D scan from a machined 1.5 mm crown and a "preparation" optical 3D scan of the reduced zirconia abutment [29].

The machining of all crowns was done using two CAM units (Cerec 3 no. 01307 and 01428, Sirona) equipped with standard cylinder and conical burs, both with ∅ 1.6 mm and D 64 µm diamond coating. New burs were used for each new crown series (n = 15). The crown material was esthetic ceramic (Vitablocs Mark II, Vita Zahnfabrik, Bad Säckingen, Germany).

Before cementation of the crowns both titanium (1) and zirconia (2) abutments were air-abraided using alumina powder (110 µm grain size) from a distance of 5 mm at two bar pressure, and the screw access openings of the abutments were closed with provisional light curing resin (Fermit, Ivoclar Vivadent) and light cured (60 s) in all groups. 15 crowns each with 0.5 mm and 1.5 mm occlusal thickness were fabricated and placed ‘not cemented’ (a) as controls on the titanium (1) and zirconia (2) abutmens to be loaded until fracture. After this, 15 crowns each with 0.5 mm and 1.5 mm occlusal thickness were cemented non-adhesively (b) using glassionomer cement (Ketac Cem, 3M Espe, Seefeld, Germany) on titanium (1) and zirconia (2) abutments serving as additional control groups. For cementation the crowns were filled with Ketac Cem, placed on the abutments and held in position exerting constant finger pressure for 3 min. Excess material was removed after 10 min using an explorer (EXD 5, Hu-Friedy, Chicago, USA). The samples were stored dry at 21°C room temperature for 24 to 48 h before load testing.

For adhesive cementation the abutments were air-abraided as above. Before using adhesive cement c (Multilink, Ivoclar Vivadent) both titanium (1) and zirconia (2) abutments were conditioned using a primer containing methacryl phosphate with methacrylate- and phosphoric esters as the reactive components (Multilink Metal Primer, Ivoclar Vivadent). The primer was thinly brushed on using microbrushes (Ivoclar Vivadent) and the abutment was blown dry after 180 s. The internal surface of the crowns was etched 60 s with 4.9% hydrofluoric acid gel (Ceramics Etch, Vita). The gel was sprayed off thoroughly (30 s) with water and the internal surface was blown dry using oil-free compressed (2 bar) air. Silane solution (Monobond S, Ivoclar Vivadent) was brushed on the internal surfaces, allowed reacting for 60 s and blown dry. 15 crowns each with 0.5 mm and 1.5 mm occlusal thickness were cemented adhesively on titanium (1) and zirconia (2) abutments using resin-based cement c. Equal parts of the two-paste material were mixed (30 s) using a plastic spatula to form a homogenous mass, applied to the internal surface and the crowns seated on the abutment and held in position exerting constant finger pressure for 3 min. Gross excess material was removed using an explorer (EXD 5, Hu-Friedy) and the cementation interface covered with oxygen protective gel (Air Block Liquid Strip, Ivoclar Vivadent). The samples were stored dry at 21°C between 24 h and 48 h until fractured.

Before using adhesive cement d (Panavia 21 TC, Kuraray, Osaka, Japan) to seat another 15 crowns each with 0.5 mm and 1.5 mm occlusal thickness on titanium (1) and zirconia (2) abutments (sandblasted as above), the titanium abutments were first conditioned with a primer containing 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) and 6- (4-Vinylbenzyl-n-propyl) amino-1, 3, 5-triazine-2, 4-dithione (VBATDT); (Alloy Primer, Kuraray). The ready solution was thinly brushed on.

Thereafter one drop of methacryl phosphate primer (ED Primer A and B, Kuraray) was mixed and the solution applied to the titanium abutment surface and gently air dried after 60 s. Equal parts of the two-paste adhesive cement d were mixed (30 s) using a plastic spatula to form a homogenous mass, applied to the internal surface, the crown seated as described above, the margins covered with oxygen protective gel (Oxyguard II, Kuraray) and curing allowed for 10 min, all other working steps were the same as with Multilink. Furthermore, 15 crowns with 5.5 mm occlusal thickness were cemented adhesively on shortened zirconia (3) abutments using adhesive cements c and d with the same working steps as described above.

All abutment crown samples were mounted into a universal testing machine (RM 50, Schenck-Trebel, 8606 Nänikon, Switzerland). A Teflon foil (0.2 mm thickness, no. 540, Angst & Pfister, Zurich, Switzerland) was placed in between the crown and the steel ball as a stress breaker (Figure 3). In each loading series (n = 15) three samples each were loaded on the same block-implant-abutment unit, i.e. crown loading was distributed on 5 block-implant-abutment units. Loading was done with a crosshead speed of 0.5 mm/min until fracture. The load force (N) was recorded on a digital display and at fracture the maximum load force (N) was displayed and entered into Excel (Microsoft Office Mac 04) tables. All fracture load data were entered into the StatView Program 4.5 (Brain Power, Calabas, USA) and are presented as box-plot diagrams. For statistical analysis we used two-way ANOVA and the one-way ANOVA Scheffé-test. Additionally, ANOVA of the fracture load values of the adhesively placed crowns only was used to analyze the variables 'occlusal thickness', 'type of adhesive' and 'type of abutment'. Weibull probability plots for failure of esthetic ceramic CAD/CAM generated crowns with 1.5 mm occlusal thickness placed with adhesive cements c and d on titanium and zirconia implant abutments were calculated using Minitab 14 Software (Minitab Inc. Pennsylvania, USA) [30].

3. Results

Fracture load (N) data are presented in Table 2 and in Figures 4 to 6.

The occlusal crown thickness influenced fracture load data. Occlusal thickness of 1.5 mm generally showed significantly ($P<0.001$) higher fracture load (N) than 0.5 mm occlusal thickness, except those seated with adhesive cement d) on titanium abutments (Fig. 4).

Two-way ANOVA revealed interaction between abutment material and mode of cementation. The abutment material influenced fracture load in that values on titanium were generally higher ($P<0.05$-0.001) than on zirconia abutments for both adhesive cements (Table 2).

Mode of cementation influenced fracture load data. Adhesive cementation generally resulted in higher fracture loads than non-adhesive cementation. On titanium (1) abutments, crowns with 0.5 and 1.5 mm occlusal thickness showed significant ($P<0.001$) increase of strength between non-adhesive 1b and adhesive 1c as well as 1d cementation (Fig. 4). On zirconia (2) abutments, crowns with 1.5 mm occlusal thickness showed strengthening by adhesive 2d ($P<0.001$) versus non-adhesive 2b cementation (Fig. 5).

Reduced height of zirconia abutment associated with increased thickness (5.5 mm) of adhesive crowns resulted in the same (3c, $P>0.05$) or less (3d, $P<0.001$) fracture strength compared to 1.5 mm occlusal thickness crowns (Fig. 6).

The type of adhesive cement influenced fracture load data. On titanium abutments (1) crowns with 0.5 mm occlusal thickness, cemented with adhesive cement d were significantly ($P<0.001$) stronger than adhesive 1c crowns while the strength of the crowns with 1.5 mm occlusal thickness was not significantly different (Fig. 4). On zirconia abutments (2) crowns cemented with adhesive cement d with occlusal thickness of both 0.5 and 1.5 mm were significantly ($P<0.05$) stronger than adhesive 2c cemented crowns (Fig. 5). The Weibull probability of failure plots for crowns with 1.5 mm occlusal thickness show the range of dependability of the crowns seated with adhesive cements c and d on titanium (Fig. 7) and zirconia (Fig. 8) implant abutments.

Mixed cohesive fracture of ceramic and cement as well as adhesive failure was seen after failure of crowns seated with adhesive cements c and d on both titanium and zirconia abutments (Fig. 9).

4. Discussion

Crown material and thickness have been identified as primary factors influencing the stress in the crown-cement-tooth system among other variables [31]. In the present study the fracture load of esthetic ceramic [11] CAD/CAM generated implant crowns was influenced by the occlusal crown thickness, abutment material, mode of cementation, type of luting agent and height of the abutment confirming our hypothesis.

To simulate the situation of an osseo-integrated implant a model taken over from other studies was used embedding the implants into a block of polymethyl-methacrylate because its modulus of elasticity is similar to that of jaw spongy bone [32, 33]. The occlusal thickness of the sample crowns was similar as used in previous in vitro studies [21, 22, 24]. The occlusal thickness of 0.5 mm was chosen as a critical mark clearly below the required minimum of 1.0 to 1.5 mm [29]. The 5.5 mm bulk thickness was chosen because it may offer potential for a particular CAD/CAM implant crown construction [34].

The mode of cementation, particularly the strengthening effect of adhesive cementation [36] strongly influenced fracture load values of esthetic ceramic implant crowns in the present study. The relatively high fracture load of non-cemented control crowns (a) was not further increased by non-adhesive cementation (b) in most groups. This may be attributed to the characteristic high initial strength of the implant crowns caused by their geometric circular internal shape and the increasingly thick lateral walls towards the occlusal. However, significant increases of strength were caused by adhesive cementation with both adhesive cements c and d. This is in concurrence with the strengthening effect of adhesive cementation as reported in other studies [21 - 24,35,36]. The high fracture load of group 1d was similar for 0.5 mm as for 1.5 mm occlusal thickness crowns indicating that the adhesion provided by cement d obviously compensated for the generally lower strength of occlusal thin (0.5 mm) crowns. In a previous study the strength increasing effect of adhesive cement also compensated for the limited material strength of esthetic ceramic crowns levelling it with the strength of lithiumdisilicate crowns [21].

Abutment material influenced fracture load values in that fracture load values on titanium abutments were throughout significantly higher than on zirconia abutments. Alumina-air-abrading and the use of a methacrylate-phosphate primer are a prerequisite of bonding with resin-based cements to titanium [37-39]. The acid phosphoric esters are bonding chemically to the metal oxide layer [37] the methacrylate providing the chemical bond to resin-based cement. While studies confirm the adhesive effects of primers to titanium by chemical bond [38-40] alumina air-abrasion appears to exert a major influence on adhesion to titanium through micromechanical retention [37, 40]. Similarly, a stable chemical bond to zirconia can be established by air abrasion of the zirconia and using a phosphate monomer (MDP)-containing resin as contained in adhesive cement d [41-44]. The chemical bond of adhesive cement c to zirconia is provided by the acid phosphoric acrylates contained in the metal primer forming a zirconia-phosphate chemical bond (manufacturer’s information, Ivoclar Vivadent 2004). Both chemical and micromechanical factors probably have contributed to the differences between bond strength to the titanium and zirconia abutments in the present study.

The type of resin-based adhesive cement influenced the fracture strength in that adhesive cement d generally showed higher fracture load values than adhesive cement c on both titanium and zirconia abutments. The Weibull probability plots for failure reveal the difference particularly on zirconia abutments. Since the details of the chemical composition of both adhesive cements are proprietary the exact mechanisms and reasons for the different performance cannot be determined here. The dependability of adhesive cement d particularly when used for the placement of zirconia ceramic restorations is well established [43]. In vitro, adhesive cement d showed excellent results after thermocycling [44]. In vivo adhesive cement d has since proved itself very well for cementation of zirconia fixed partial dentures [45].

Occlusal crown thickness consistently influenced the fracture load of the implant abutment crowns comparing 0.5 and 1.5 mm thickness being in concurrence with fundamental materials knowledge [31]. However, increasing the thickness of the crown to the unusual 5.5 mm in combination with the shortening of the abutments of group 3 did not result in higher crown strength. The reduced supporting area of the shortened abutment and the increased probability of the inclusion of fracture inducing flaws with higher thickness may have opposed the further increase of strength and limited strengthening by added thickness [46].

Crowns loaded to fracture on both titanium and zirconia abutments showed a mixture of cohesive fracture of resin cement and ceramic as well as adhesive failure in the present study appearing similar to mixed modes of fracture at titanium interfaces as reported in another study [40]. This particular fracture mode together with the high fracture load values indicates strong adhesive effects at the abutment-cement and cement-crown interfaces for both abutments and both adhesive cements.

In conclusion, the present study confirmed the reinforcing effects of adhesive cements for esthetic ceramic CAD/CAM implant crowns on titanium and zirconia abutments. Although the strength of the esthetic ceramic is limited [11] the high fracture load values obtained with adhesive cementation in the present study indicate that esthetic ceramic may fulfill the demands for adequate strength of implant crowns if seated with adhesive cements.

Acknowledgments

We are grateful to Dr. G. Menghini, Department of Preventive Dentistry, Periodontology and Cariology, for his assistance in preparing the statistical analysis and we thank Malgorzata Roos Department of Social- and Preventive Medicine for additional help with the Weibull analysis. The support by Olivier Loeffel, Department of Crown and Bridge Prosthodontics and Dental Materials, with load testing was very much appreciated. This study was supported by the Foundation for the Advancement of Computer-Assisted Dentistry at the University of Zurich.

References

[1] Hansen S. Cerec - chairside fabrication of superstructures for immediately loaded implants. In: Mörmann WH (ed). State of the art of CAD/CAM restorations, 20 years of Cerec. Berlin: Quintessence, 2006:173-180.

[2] Avivi-Aber L, Zarb GA. Clinical effectiveness of implant-supported single-tooth replacement: The Toronto Study. Int J Oral Maxillofac Implants 1996;11:311-21.

[3] Scheller H, Kultje C, Klineberg I, Goldberg P V, Stevenson-More P Alonso J M N, Schaller M, Corria R M, Engquist B, Toreskog S, Kastenbaum F, Smith C R. A 5-year multicenter study on implant-supported single crown restorations. Int J Oral Maxillofac Implants 1998;13:212-8.

[4] Prestipino V, Ingber A. Esthetic high strength implant abutments. Part I. J Esthet Dent 1993(a);4:29-35.

[5] Prestipino V, Ingber A. Esthetic high strength implant abutments. Part II. J Esthet Dent 1993 (b);5:63-68.

[6] Wohlwend A, Studer S Schärer P. The zirconium oxide abutment: An all ceramic abutment for esthetic improvement of implant suprastructures. QDT 1997;1:63-72.

[7] Yilderim M, Fischer H, Marx R, Edelhoff D. In-vivo fracture resistance of implant-supported all-ceramic restorations. J Prosthet Dent 2003(b);90:325-31.

[8] Tinschert J, Zwez D, Marx R. Anusavice KJ.Structural reliability of alumina-, feldspar-, leucite-, mica- and zirconia-based ceramics. J Dent 2000;28:529-35.

[9] Filser F, Kocher P, Weibel F, Lüthy H, Schärer P, Gauckler LJ. Reliability and strength of all ceramic dental restorations fabricated by direct ceramic machining (DCM). Int J Comp Dent 2001;4:89-106.

[10] Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. Dent Mater 2004;20:449-456.

[11] Kelly JR. Machinable ceramics. In: Mörmann WH (ed). State of the art of CAD/CAM restorations, 20 years of Cerec. Berlin: Quintessence, 2006:29-38.

[12] Bindl A, Lüthy H, Mörmann WH. Fracture load of CAD/CAM-generated slot-inlay FPDs. Int J Prosthodont 2003;16:653-660.

[13] Andersson B, Ödman P, Lindvall A-M, Brånemark P-I. Cemented single crowns on osseointegrated implants after 5 Years: results from a prospective study on CeraOne. Int J Prosthodont 1998;11:212-218.

[14] Prestipino V, Ingber A, Kravitz J. Clinical and laboratory consideration in the use of a new all-ceramic restorative system. Pract Periodontics Aesthet Dent 1998;10:567-575.

[15] Helkimo E, Carlson GE, Helkimo M. Bite force and state of definition. Acta Odontol Scand 1977;35:297-303.

[16] Waltimo A, Könönen M, A novel bite force recorder and maximal isometric bite force values for healthy young adults. Scand J Dent Res 1993;101:171-175.

[17] Waltimo A, Kemppainen P, Könönen M. Maximal contraction force and endurance of human jaw-closing muscles in isometric clenching. Scand J Dent Res 1993;101:416-21.

[18] Esquivel-Upshaw JF, Anusavice KJ, Young H, Jones J, Gibbs C. Clinical performance of a lithia disilicate-based core ceramic for three-unit posterior FPDs. Int J Prosthodont. 2004;17:469-475.

[19] Peterson IM, Wuttiphan S, Lawn BR, Chyung K, Role of microstructure on contact damage and strength degradation of micaceous glass-ceramics. Dent Mater 1998;14:80-89.

[20] Jung YG, Peterson IM, Kim DK, Lawn BR. Lifetime-limiting Strength degradation from contact fatigue in dental ceramics. J Dent Res 2000;79:722-731.

[21] Bindl A, Lüthy H, Mörmann WH. Strength and fracture pattern of monolithic CAD/CAM-generated posterior crowns. Dent Mater 2006;22:29-36.

[22] Mörmann WH, Bindl A, Lüthy H, Rathke A. Effects of preparation and luting system on all-ceramic computer-generated crowns. Int J Prosthodont 1998; 11:333-339.

[23] Kümin P, Lüthy H, Mörmann WH. Strength of ceramic and polymer after CAD/CAM-milling and bonded to dentin. Schweiz Monatsschr Zahnmed 1993; 103: 17-24. (German)

[24] Lampe K, Lüthy H, Mörmann WH. Fracture load of all-ceramic computer crowns. In: WH Mörmann, (ed). CAD/CIM in aesthetic dentistry, Cerec 10 year anniversary symposium. Chicago: Quintessence, 1996:463-482.

[25] Bindl A, Richter B, Mörmann WH. Survival of ceramic computer-aided desingn/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont 2005;18:219-224.

[26] Bindl A, Mörmann WH. Cerec implant crowns on ceramic abutments. In: Mörmann WH (ed). State of the art of CAD/CAM restorations, 20 years of Cerec. Berlin: Quintessence, 2006:155-162.

[27] Zöllner A, Benthaus K. Cerec labside implant restorations: custom made abutments. In: Mörmann WH (ed). State of the art of CAD/CAM restorations, 20 years of Cerec. Berlin: Quintessence, 2006:163-172.

[28] Lysell L, Myrberg N. Mesiodistal tooth size in the deciduous and permanent teeth. Eur J Orthodontics 1982;4:113-122.

[29] Ender A, Mörmann WH. Cerec 3 D Design: all-ceramic CAD/CAM inlays, partial crowns, full crowns and veneers, construction und fabrication by computer. Zurich: Foundation for the Advancement of Computerized Dentistry, 2005: (German)

[30] McCabe JF, Carrick TE. A statistical approach to the mechanical testing of dental materials. Dent Mater 1986;2:139-42.

[31] Rekow ED, Harsono M, Janal M, Thompson V, Zhang G. Factorial analysis of variables influencing stress in all-ceramic crowns. Dental Materials 2006; 22:125-132.

[32] Tripodakis AP, Strub JR, Kappert HF Witkowski S. Strength and mode of failure of single implant all-ceramic abutment restorations under static load. Int J Prosthodont 1995; 8: 265-75.

[33] Behr M, Rosentritt M, Lang R, Handel G. Glass fiber-reinforced abutments for dental implants, a pilot study. Clin Oral Impl Res 2001;12:174-178.

[34] Wolf BD, Fracture load of monolithic CAD/CAM generated crowns on titanium and zirconia implant abutments with non-adhesive and adhesive cementation. Doctoral Thesis University of Zurich 2006. (German)

[35] Burke FJT, Fleming G, Nathanson D, Marquis PM. Are adhesive technologies needed to support ceramics? An assessment of the current evidence. J Adhes Dent 2002;2:7-22.

[36] Addison O, Marquis PM, Fleming GJP. Resin elasticity and the strengthening of all-ceramic restorations. J Dent Res 2007;86:519-523.

[37] Taira Y, Matsumura H, Yoshida K, Tanaka T, Atsuta M. Influence of surface oxidation of titanium on adhesion. J Dent 1998;26:69-73.

[38] Taira Y, Yanagida H, Matsumura H, Atsuta M. Effects of a metal etchant and two primers on resin bonding durability to titanium. Eur J Oral Sci 2004;112: 95-100.

[39] Tsuchimoto Y, Yoshida Y, Takeuchi M, Mine A, Yatani H, Tagawa Y, Van Meerbeek B, Suzuki K, Kuboki T. Effect of surface pretreatment on durability of resin-based cements bonded to titanium. Dental Materials 2006;22:545-552.

[40] Schneider R, Fernando deGoes M, Pessanha Henriques GE. Chan DCN. Tensile bond strength of dual curing resin-based cements to commercially pure titanium. Dental Materials 2007;23:81-87.

[41] Kern M, Wegner S. Bonding to zirconia ceramic: adhesion methods and their durability. Dent Mater. 1998;14:64-71.

[42] Wolfart M, Lehmann F, Wolfart S, Kern M. Durability of the resin bond strength to zirconia ceramic after using different surface conditioning methods. Dental Materials 2007;23:45-50.

[43] Blatz MB, Sadan A, Martin J, Lang B. In vitro evaluation of shear bond strengths of resin to densely-sintered high-purity zirconium-oxide ceramic after long-term storage and thermal cycling. J Prosthet Dent 2004;91:356-362.

[44] Lüthy H, Loeffel O, Hämmerle CH. Effect of thermocycling on bond strength of luting cements to zirconia ceramic. Dent Mater. 2006;22:195-200.

[45] Sturzenegger B, Fehér A, Lüthy H, Schumacher M, Loeffel O, Filser F, Kocher P, Gauckler L, Scharer P. Clinical study of zirconium oxide bridges in the posterior segments with the DCM system. Schweiz Monatsschr Zahnmed 2000;110:131-139.

[46] Marx R. Modern ceramic materials for esthetic restorations – strengthening and fracture toughness. (German) Dtsch Zahnärztl Z 1993; 48: 229-236.

Figures

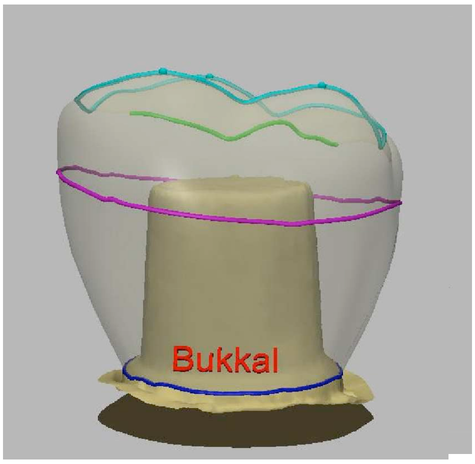

Figure 1

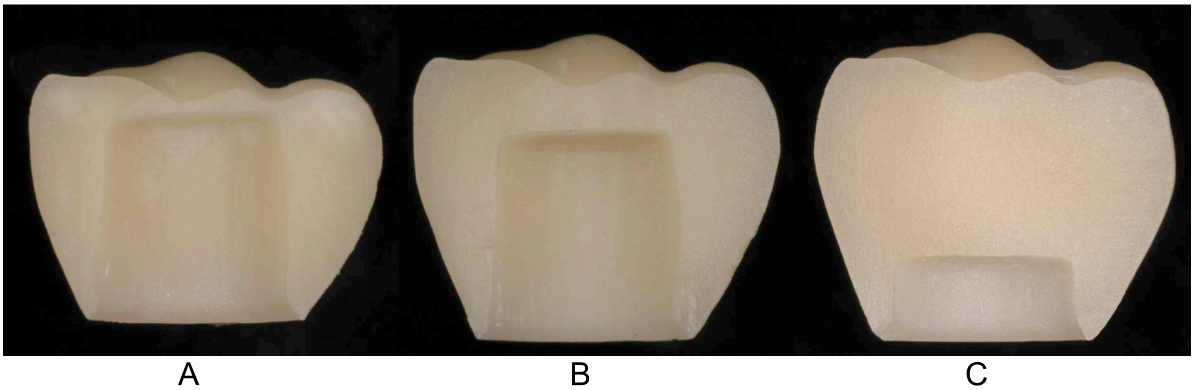

Figure 2

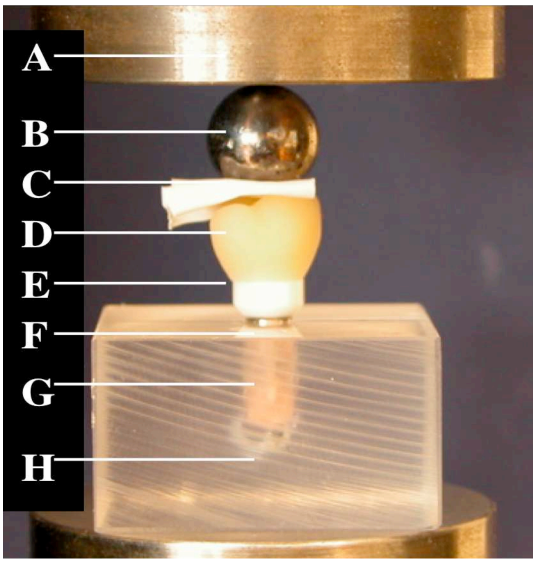

Figure 3

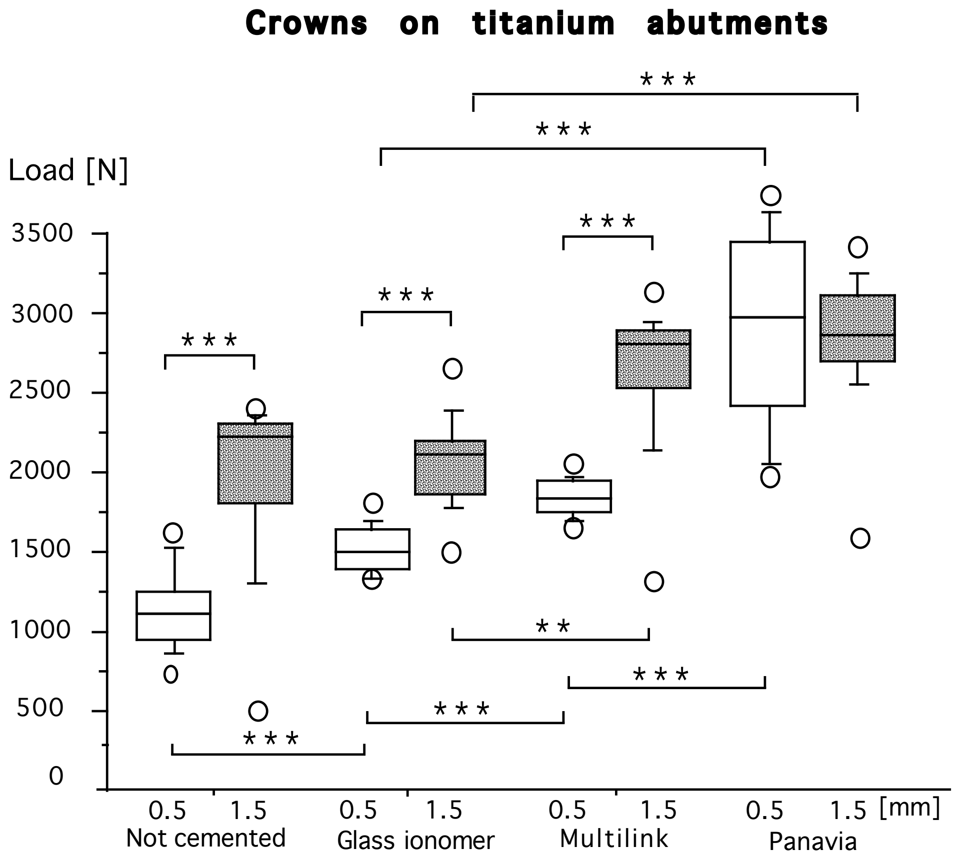

Figure 4

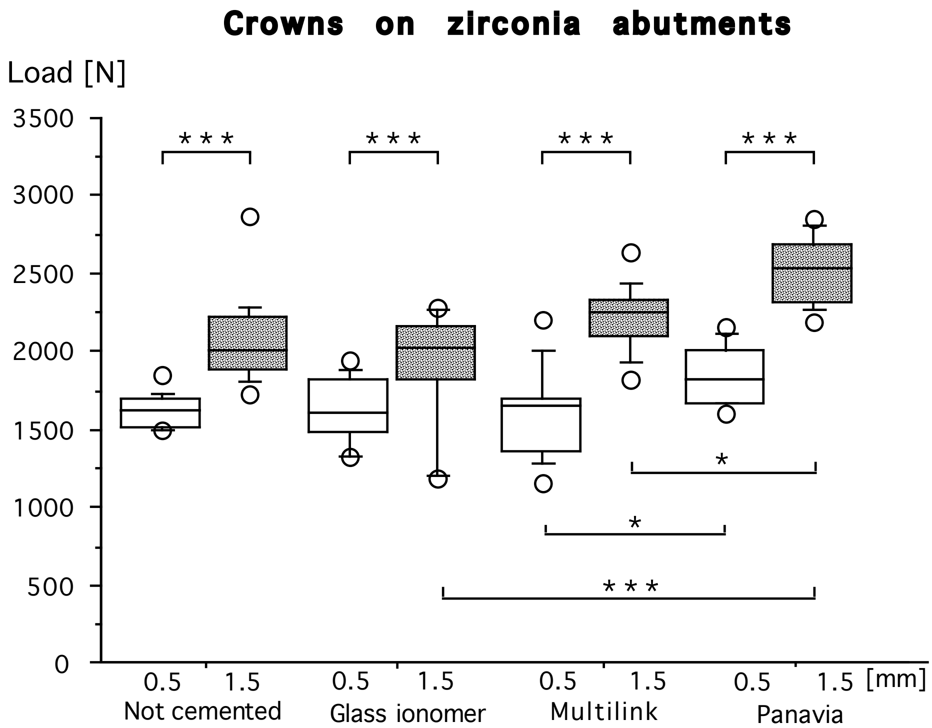

Figure 5

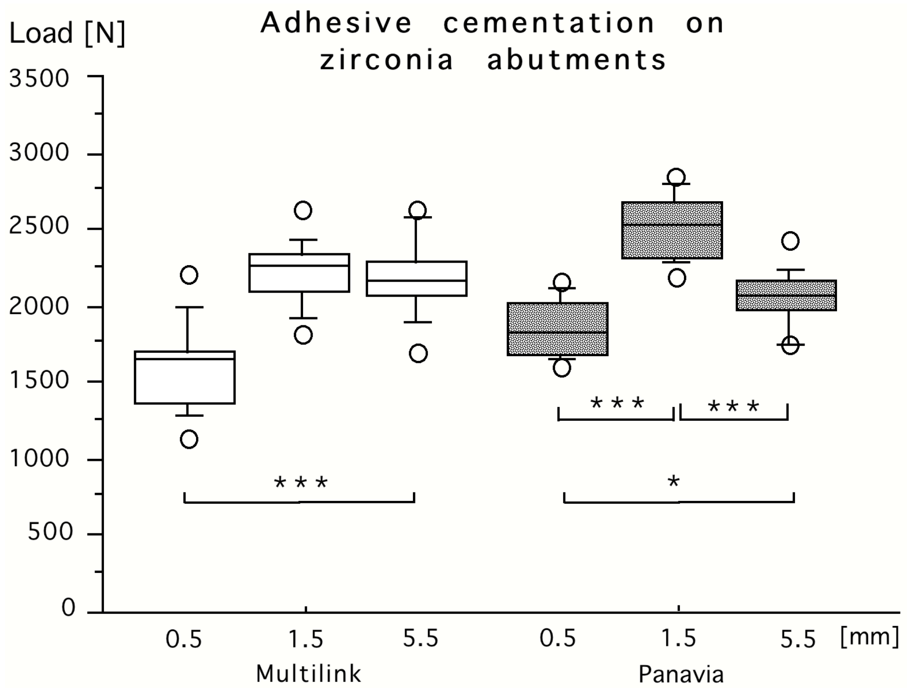

Figure 6

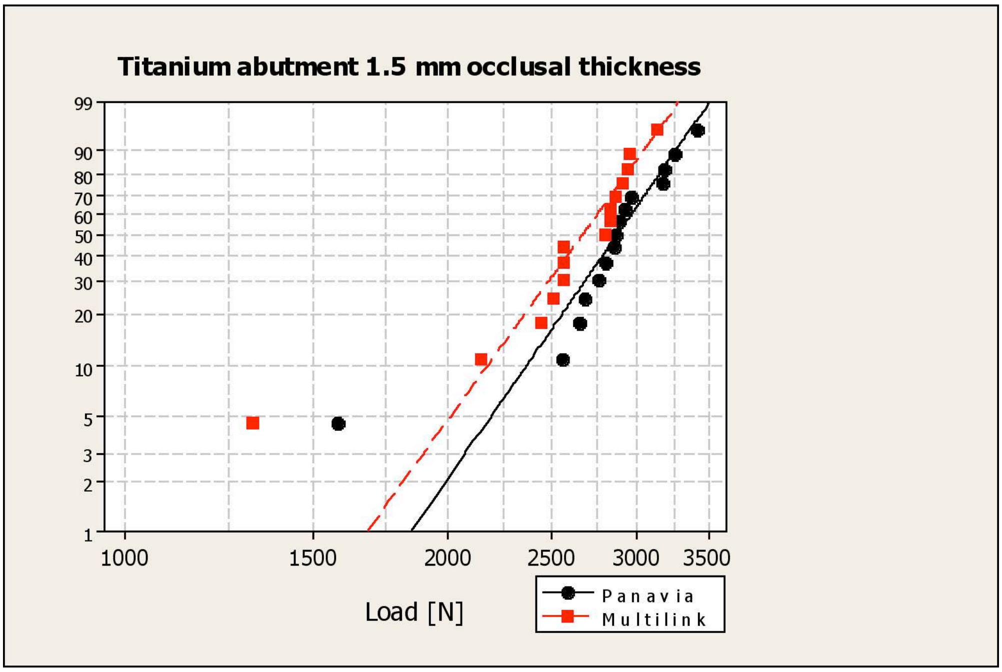

Figure 7

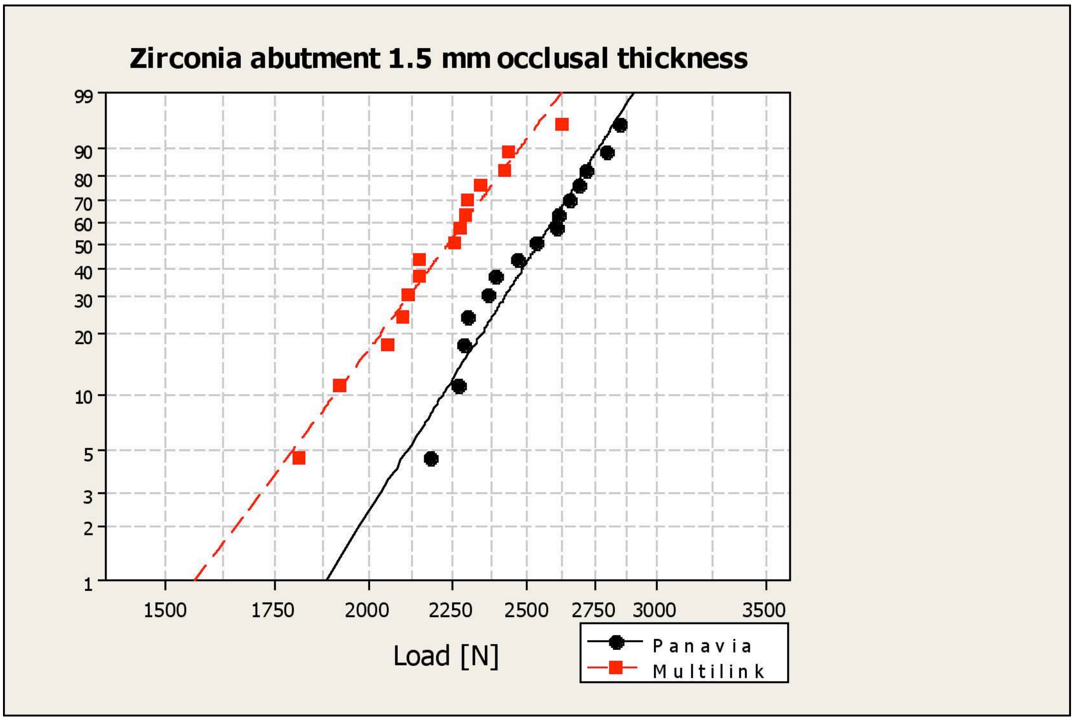

Figure 8

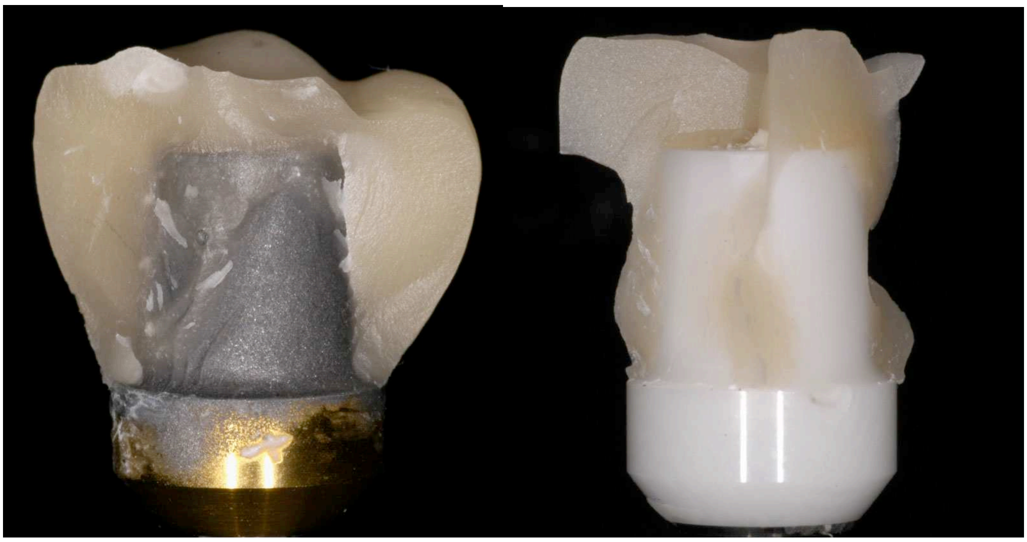

Figure 9

Legends

Figure 1 Construction lines of the sample crown as designed on the standard abutment representing the identical form of the titanium (Gingihue) and zirconia (ZiReal) abutments used in this study, shown in the "edit" mode of the CAD design software (Cerec R 1500, german version). "Bukkal" indicates buccal aspect of the crown.

Figure 2 CAD/CAM generated esthetic ceramic sample crowns with A) 0.5 mm, B) 1.5 mm occlusal thickness and identical internal shape; C) 5.5 mm occlusal thickness on shortened abutment; identical occlusal shape of A, B and C.

Figure 3 Loading until fracture: A) Loading stamp, B) Steel ball, C) Teflon foil, D) Sample crown, E) Abutment, F) Fixture, G) Implant, H) Polymethylmethacrylate supporting block.

Figure 4 Box-plot diagram of fracture loads (N; n=15) of esthetic ceramic CAD/CAM crowns with 0.5 and 1.5 mm occlusal thickness on titanium abutments (1): non-cemented (a); cemented with glassionomer cement (b), adhesive cements c and d; significant differences *** $P< 0.001$; ** $P< 0.01$; Scheffé-tests.

Figure 5 Box-plot diagram of fracture loads (N; n=15) of esthetic ceramic CAD/CAM crowns with 0.5 and 1.5 mm occlusal thickness on zirconia abutments (2): non-cemented (a); cemented with glassionomer cement (b), adhesive cements c and d; significant differences*** $P< 0.001$; ** $P< 0.01$; * $P< 0.05$, Scheffé-tests.

Figure 6 Box-plot diagram of fracture loads (N; n=15) of esthetic ceramic CAD/CAM crowns with 0.5, 1.5 mm occlusal thickness on standard zirconia abutments (2) and with 5.5 mm occlusal thickness on shortened (3) zirconia abutments. All crowns seated with adhesive cements c and d. Significant differences*** P< 0.001; * P< 0.05, Scheffé-tests.

Figure 7 Probability plot for failure of esthetic ceramic CAD/CAM generated crowns with 1.5 mm occlusal thickness placed with adhesive cements c (Multilink) and d (Panavia) on titanium implant abutments. The lowest value for Multilink was related to a sample crown showing a hairline crack before loading. The lowest value for Panavia was related to a chipping fracture. The steepness of the line is a measure for the dependability of the material [30].

Figure 8 Probability plot for failure of esthetic ceramic CAD/CAM generated crowns with 1.5 mm occlusal thickness placed with adhesive cements c (Multilink) and d (Panavia) on zirconia implant abutments. The steepness of the lines indicates range of dependability. The steepness of the line is a measure for the dependability of the material [30].

Figure 9 Esthetic ceramic CAD/CAM crowns with 1.5 mm occlusal thickness seated with adhesive cement d on titanium (A) and zirconia (B) abutments after loading until fracture. Rests of cement and of ceramic adhere to both abutments indicating mixed cohesive cement and ceramic fracture as well as adhesive failure.

Table 1 Materials and instruments used in this study.

CAD/CAM block ceramic, Vitablocs Mark II, size I14, lot 7535 and 7542	Vita Zahnfabrik, Bad Säckingen, Germany
Titanium (1) abutment, Gingihue, IWPP574G	3i Implant Innovations, Palm Beach, USA
Zirconoxide (2) abutment, ZiReal IWCAP574	3i Implant Innovations
Self-cure PMMA, Paladur	Heraeus Kulzer, Dormagen, Germany
Surgident Periphery Wax, no. 92189	Heraeus Kulzer
Resin-based posterior composite Tetric A3 lot E53622	Ivoclar Vivadent Schaan, Liechtenstein
Light-cure provisional filling material, Fermit	Ivoclar Vivadent
Optical scanning surface agent Dentaco Scan'spray, lot 865773	Dentaco, Bad Homburg, Germany
Glass ionomer cement (b) Ketac Cem, lot 216105	3M Espe, Seefeld, Germany
Metal Primer, lot H20614	Ivoclar Vivadent
4.9% hydrofluoric acid gel, Ceramics Etch	Vita
Silane agent, Monobond, lot H08177	Ivoclar Vivadent
Resin-based cement (c), Multilink, lot H00866 G15780	Ivoclar Vivadent
Protection gel, Air Block Liquid Strip	Ivoclar Vivadent
Resin-based cement (d). Panavia 21 21 TC lot Nr. 0032A	Kuraray, Osaka, Japan
Alloy Primer Lot 190BA	Kuraray,
ED Primer liquid A Lot 0209A	Kuraray
ED Primer liquid B Lot 0134C	Kuraray
Oxyguard II	Kuraray
Load stress-breaker, Teflon foil, 0.2 mm, no. 540	Angst & Pfister, Zurich, Switzerland
Cerec cylinder ∅ 1.6 mm diamond bur, D 64 µm	Sirona, Bensheim, Germany no. 54 66 193
Cerec conical ∅ 1.6 mm, diamond bur, D 64 µm	Sirona no. 58 55 734

Table 2 Titanium vs. zirconia abutments: fracture load (N) ($\bar{x}$±SD; n=15) of esthetic ceramic CAD/CAM-generated crowns seated with adhesive and non-adhesive cements. P-values and levels of significance are presented.

Fracture Load of Cerec Mark II Crowns on Implant-Abutments

Occlusal Thickness	Cement	Code	Titanium (1)	Zirconia (2)	P	Significance
0.5 mm	Ketac	b	1517±156	1634±211	0.09	P>0.05
1.5 mm	Ketac	b	2072±290	1921±337	0.2	P>0.05
0.5 mm	Multilink	c	1838±115	1615±284	0.009	P<0.01
1.5 mm	Multilink	c	2625±441	2217±208	0.003	P<0.01
0.5 mm	Panavia	d	2928±590	1851±183	0.0001	P<0.001
1.5 mm	Panavia	d	2836±420	2517±209	0.014	P<0.05

P = Scheffé Test.